Decompression Theory and Physiology

Presented by the NOAA Diving Center
Seattle, Washington

Global View

- Early discoveries of decompression sickness
- Bubble dynamics
- Types, signs & symptoms, and treatment of DCS
- Haldane's Theory
- U.S. Navy Modifications

Early Discoveries of DCS-1

- In 1670, Robert Boyle used an air pump to increase the pressure within a container which housed a snake
- Upon release of the pressure the snake writhed in pain and Boyle noticed that a bubble had formed in the fluid of the snake's eye and other parts of its body
- Boyle concluded that the phenomenon was caused by decompression

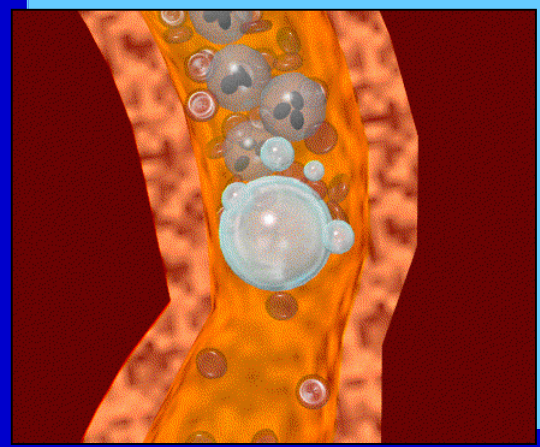
Early Discoveries of DCS-2

- In 1841, decompression sickness was observed in caisson workers who had worked in tunnels dug through wet soil
- The pressure of the air in the tunnels had been raised in order to prevent the water from entering into, and flooding, the tunnels
- The workers would spend many hours breathing the compressed air within the tunnel and would often suffer pains and other disorders after returning to normal environmental pressure

Early Discoveries of DCS-3

- “Bends” is a term first coined by workers during the construction of the St. Louis bridge around 1869-1874
- A workman walking with a difficult step and a slight stoop was similar to an affected gait by the young ladies of that time know as “Grecian bends”

Decompression Sickness-1



- Decompression sickness (DCS) is caused by the formation and growth of nitrogen bubbles in the body that result from too rapid a reduction of pressure and other factors
- The respiratory process can eliminate excess nitrogen from the body unless the nitrogen comes out of solution too rapidly and forms bubbles
- Bubbles become lodged in various parts of the body affecting normal functioning

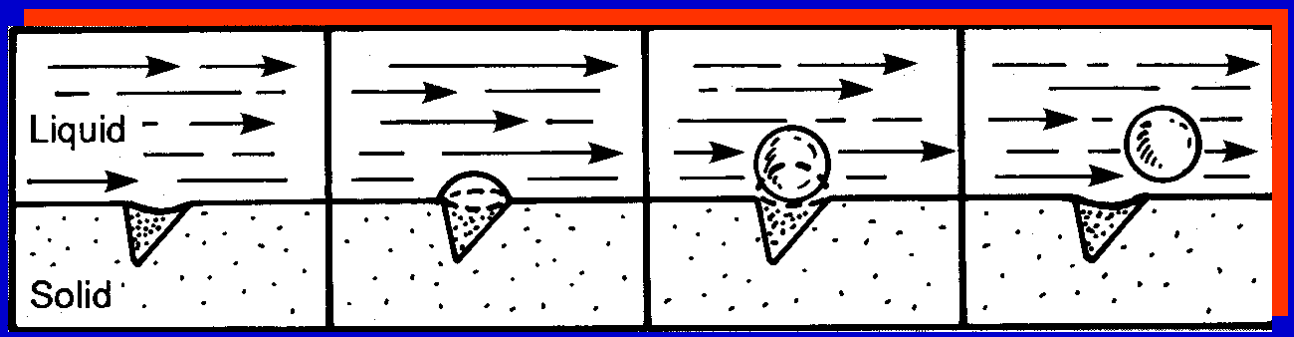
Effects of Bubbles

- Tissue damage
  - Bubbles in blood obstruct blood vessels in vital organs
  - Bubbles in tissues may press upon blood vessels obstructing blood flow
- Complementary effects
  - Bubbles in blood can stimulate blood clotting which can obstruct blood flow
  - Bubbles are perceived as being a foreign body, thus triggering formation of chemical processes to surround and attack the bubble

Bubble Formation-1

- Causes:
  - Exact cause unknown
  - Ambient pressure reduction
  - Low pressure areas (joints)
  - Cavitation & turbulence
  - Microbubble nuclei
- Types:
  - “Silent” (asymptomatic)
  - DCS (symptomatic)

Silent bubbles are estimated to be as much as 5% of N_2 taken up



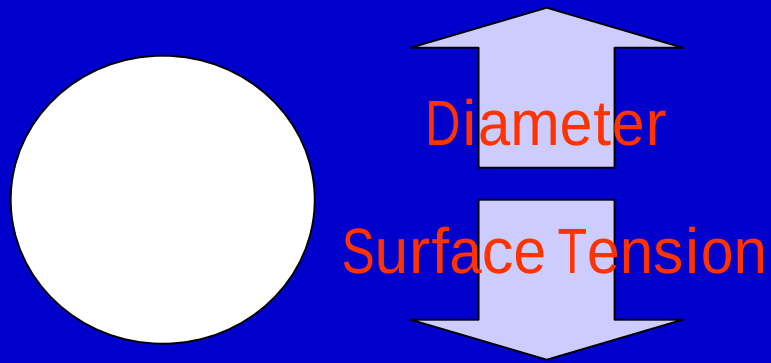
Bubble Formation-2

- The type of dive has a significant bearing on where and when bubble formation takes place
  - Short deep dives (>100') tend to cause bubble formation in the fast tissues (only fast tissues on-gas enough N_2 to form bubbles on ascent)
  - Long shallow dives tend to produce bubbles in the slow tissues (fast tissues eliminate their relatively modest N_2 excess before a critical pressure differential develops)
  - Long deep dives cause bubble formation in all tissues

Bubble Anatomy

- Composition:
- Surface tension:
  - The cohesive force that holds a bubble together
  - As diameter increases, surface tension decreases

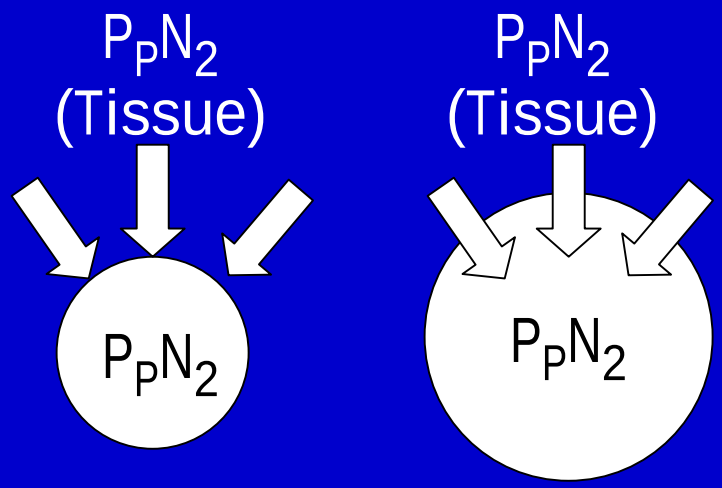
AGE Bubbles	DCS Bubbles
78% N_2	99% N_2
21% O_2	<1% CO_2
<1% Argon	<1% H_2O
<1% CO_2	
<1% H_2O	



Bubbles in the body from diving are Nitrogen bubbles

Bubble Growth

- Increasing diameter (Boyle's Law) +
- Increasing gas tension (Henry's Law) =
- Increased diameter and decreased surface tension
- Growth begins when tissue PN_2 exceeds bubble PN_2



Bubbles can become a "reservoir" for tissue gas

Decompression Sickness-2

- Causes:
  - Ascent to sea level
  - Ascent to higher elevations
- Onset of symptoms:
  - Majority will manifest within first 6 hours
  - 50% within the first hour
  - Delay in onset of 24 hours or greater has been described

In general, the earlier the symptoms, the more potentially serious the case

Decompression Sickness-3

- Types of DCS
  - Muscular-skeletal
  - Neurological
  - Inner ear
  - Pulmonary
  - Skin
- Classification of DCS
  - Type I
    - Muscular-skeletal (pain-only)
    - Skin
    - “Niggles”
  - Type II
    - Muscular-skeletal (radiating)
    - Neurological
    - Inner ear
    - Pulmonary

Contributing Factors in DCS

- Primary factors and conditions:
  - Depth
  - Dive duration
  - Decompression
- Secondary factors:
  - Obesity
  - Age
  - Fatigue
  - Smoking
  - Alcohol consumption
  - Circulatory impairment
  - Prior DCS
  - Cold or arduous dives
  - Post-dive exertion
  - Dehydration

Muscular-Skeletal DCS

- Cause: Bubbles in or near one of the muscles or tendons around the joints
  - Shoulder (most common)
  - Elbows
  - Wrists
  - Hands
  - Hips
  - Knees
  - Ankles

Most common type of DCS from shallow diving

- Signs & symptoms:
  - Discomfort or abnormal feeling in or near joint
  - Constant aching pain
  - Usually not tender to touch but aggravated when moved
  - No outward change in appearance

Not unusual for multiple joints to be affected, most notably adjacent one, i.e. shoulder & elbow same side

Neurological DCS-1

- Cause: Bubbles in or around the brain and/or spinal cord affecting the central nervous system and interfering with:
  - Sensation: sight, hearing, smell, taste, pain, and touch
  - Movement: ability to move and/or coordinate muscles, strength of movement
  - Consciousness: orientation, thinking, speech and memory
  - Autonomic functions: interference with control of breathing, heart function, bladder and/or bowel
  - Reflexes

Neurological DCS-2

- Signs & symptoms:
  - Headache
  - Numbness or tingling
  - Weakness or paralysis
  - Nausea
  - Loss of bladder/bowel control
  - Extreme fatigue
  - Visual disturbances
  - Difficulty standing or walking
  - Chest pain
  - Shortness of breath
  - Behavioral changes
  - Feeling of “something’s wrong”

Inner Ear DCS

- Cause: Bubbles in the cochlea of the inner ear affecting hearing and/or balance
- Signs and symptoms:
  - Hearing loss
  - Tinnitus (ringing in ears)
  - Vertigo
  - Nausea vomiting
  - Lack of coordination

Typically associated with deep diving

Initial diagnosis may be indistinguishable from inner ear barotrauma

Also known as vestibular DCS

Pulmonary DCS

- Cause: Bubbles trapped in the small vessels of the lungs obstructing blood flow and gas exchange
- Signs and symptoms:
  - Breathlessness known as “chokes”
  - Tight feeling in chest
  - Chest pain
  - Rapid breathing

Initial diagnosis may be indistinguishable from heart attack

Also associated with deep diving

Skin Manifestations of DCS

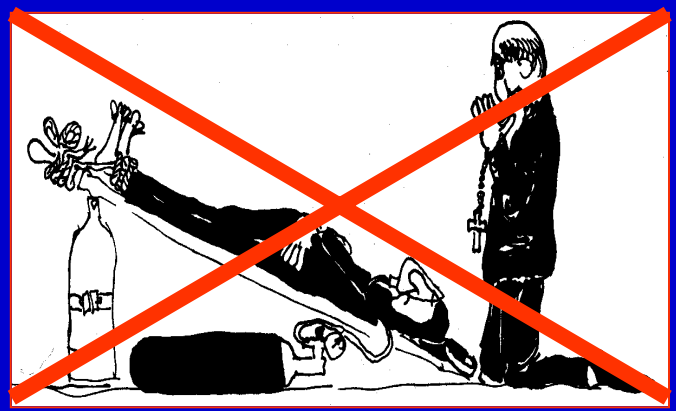
- Cause: Bubbles off-gassing through the skin
- Signs and symptoms:
  - Itching of arms and legs
  - Rash
  - Marbling (patchy white, blue and pink areas)
  - Localized swelling of skin

Common after recompression chamber or dry suit dives

Condition is not serious and requires no treatment

Treatment for DCS

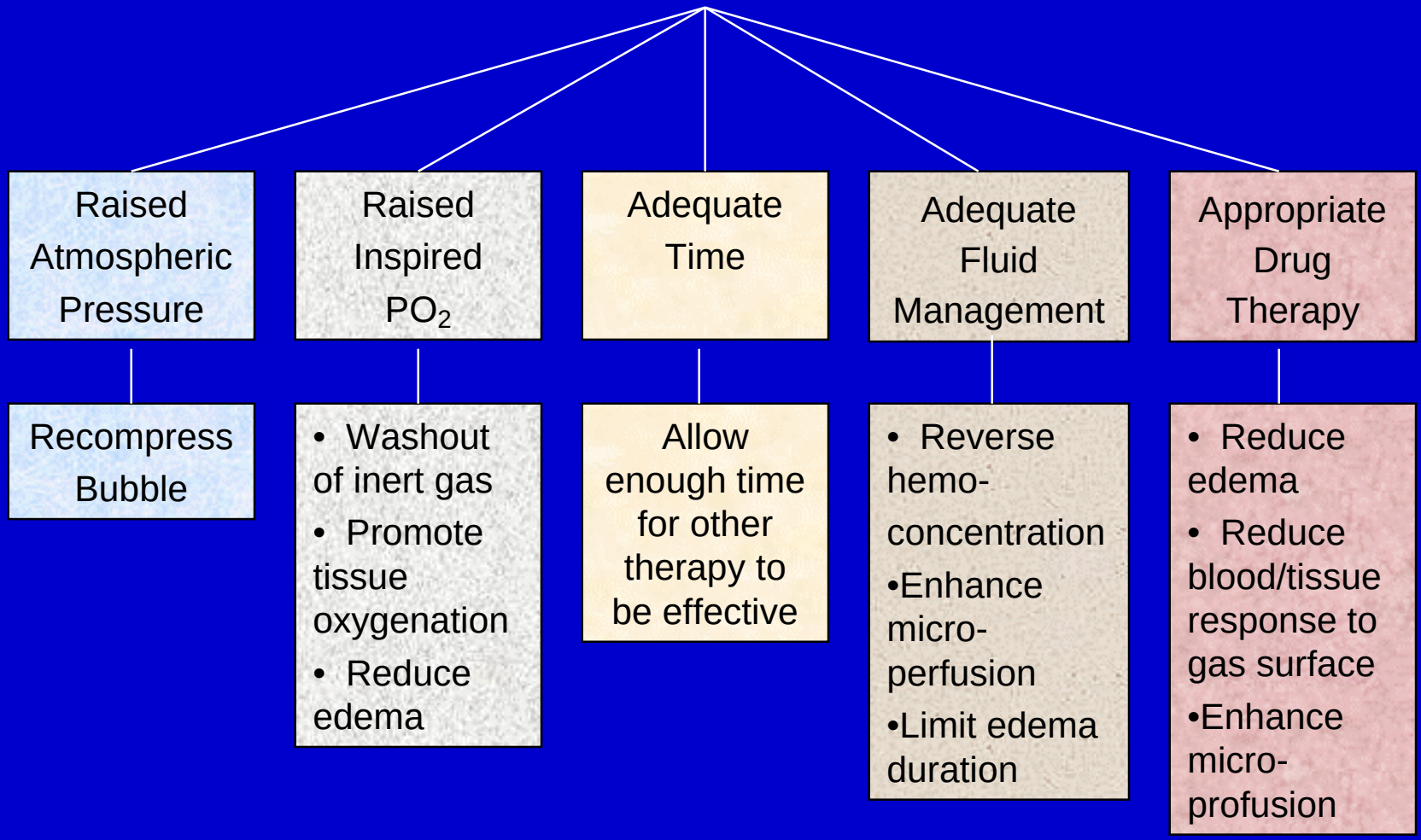
- Treatment:
  - ABCs
  - Keep victim horizontal
  - Administer 100% oxygen
  - Encourage conscious patient to drink water
  - Get victim to nearest medical facility
  - Perform field neurological exam every 15 minutes
  - Hyperbaric oxygen therapy required



Hyperbaric Oxygen Therapy

- Hyperbaric oxygen (HBO) therapy is the inhalation of 100% oxygen by a patient exposed to elevated ambient pressure in a chamber

Fundamentals of HBO Therapy-1



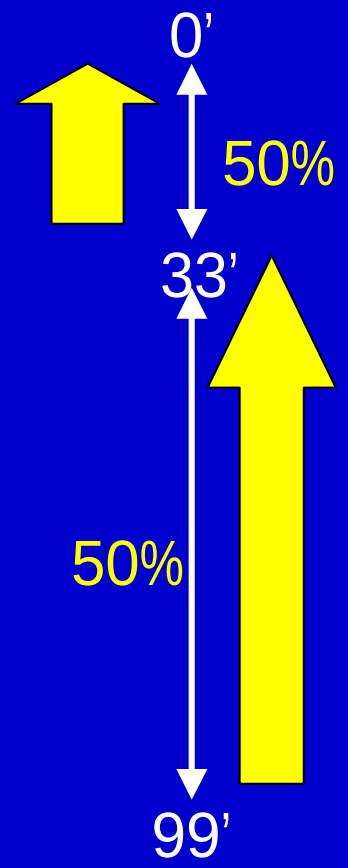
From: Rutkowski, Jan. 1991

Prevention of DCS

- Prevention:
  - Minimize predisposing factors
  - Dive conservatively:
    - Shorter bottom times
    - Longer surface intervals
    - Slower ascents
  - Safety decompression Stops
  - Decompression (ascents & stops) is the process of systematically reducing the pressure gradient between a diver's tissues and the ambient water pressure at a rate that prevents bubble growth
  - Time at depth and ascent rate limits help ensure the safe elimination of nitrogen from a diver's body

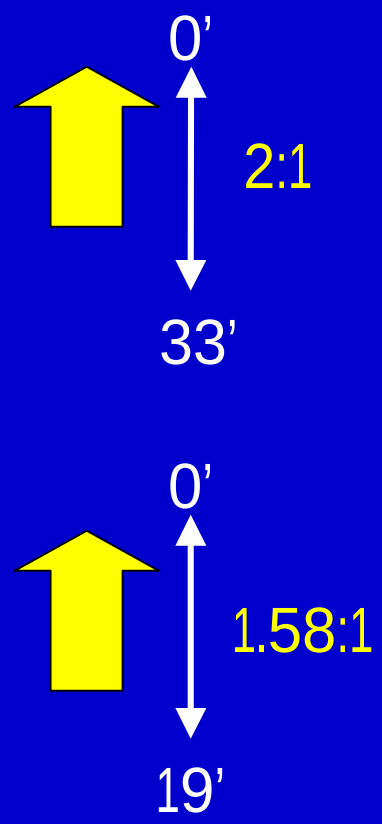
The Haldanian Theory

- J. S. Haldane, British physiologist in the early 1900's, theorized that tissues could withstand a 50% pressure reduction without bubble formation
- Haldane used 5 tissue compartment models: 5, 10, 20, 40, and 75 minutes
- The 2:1 Haldane ratio was too liberal and had to be modified



US Navy Modifications

- In 1937, the U. S. Navy modified Haldane's model and developed decompression tables:
  - Modified surfacing ratio from 2:1 to 1.58:1 (ignored oxygen component)
  - Modified compartments: 5, 10, 20, 40, 80, 120 minutes
  - Added a surface interval credit table
- The U. S. Navy Dive Tables have been tested and modified several times



Key Points-1

- Decompression sickness (DCS) was first observed in caisson workers and coined the “bends”
- DCS is caused by the formation and growth of bubbles
- Bubbles form for a variety of reasons and grow because of Boyle’s and Henry’s gas laws
- Five different types of DCS: muscular-skeletal, neurological, inner ear, pulmonary, and skin
- Treatment involves ABCs, supine position, oxygen, recompression

Key Points-2

- There are a number of ways to minimize the risk of DCS
- The gradual elimination of gas (decompression) helps prevent bubble formation and growth
- Haldane's 2:1 decompression theory was too liberal
- USN modified ratio to 1.58:1, changed the tissue half-times, and added a surface interval credit table